Broward County Ground Water Flow Model

Introduction

The District, in cooperation with the Hydrological Modeling Center at Florida Atlantic University, developed a ground water flow model of the SAS to simulate ground water conditions in central and eastern Broward County, as well as portions of northeastern Miami-Dade County and southeastern Palm Beach County. The model was completed in November, 1999. The new model was constructed and based, in part, on the initial Broward County Ground Water Flow Model developed by Restrepo et al. (1992).

Figure F-7 depicts the active model domain in relation to the predominant features of this area. The model domain was discretized horizontally using a finite-difference grid consisting of 456 rows, 371 columns, and 500-foot square cells. It was calibrated to observed water levels from the period from January 1988 to December 1995.

Physical Features

Hydrogeology and Model Layers

Only the SAS was included in the Broward County Ground Water Flow Model. The SAS within Broward County essentially consists of (in order of increasing depth) Holocene and recent sediments/soils; the Miami Limestone (formerly referred to as the Miami Oolite); the Fort Thompson formation and/or the Anastasia Formation; the upper unit of the Tamiami formation; the Gray Limestone aquifer; and the lower clastic sediments of the Tamiami formation. Deviations from this general sequence of units, however, can occur in the extreme eastern and western portions of the model domain. For further details, see Perkins (1977), Fish and Stewart (1991) and Causarus (1985).

The vertical discretization of the Broward model corresponds to the hydrostratigraphy described above. The model has five model layers. The top layer, corresponding to the youngest Pleistocene marine unit deposited in the region (referred to as Q5), generally extends from land surface to an elevation of -5 to -20 ft NGVD. Layer two consists of the next two marine Pleistocene deposits (referred to as Q4 and Q3) (Perkins, 1977). Layer three encompass the main production zone of the Biscayne aquifer, and correspond to the middle and late Pleistocene deposits of the Fort Thompson and Anastasia formations. Layer four encompasses the upper unit of the Tamiami formation. Layer five encompasses the Gray Limestone aquifer in the west, and the coastal equivalent of the lower Tamiami aquifer.

Recharge and Evapotranspiration

The models used to simulate recharge and evapotranspiration are discussed in the General Subregional Model Features section earlier in this appendix. The stations used for the Broward County Ground Water Flow Model are presented in **Figure F-8**.

Canals

The predominant canal network within the Broward County model domain is shown in **Figure F-7**. In addition to all major District canals, it includes numerous lakes and secondary canals in the region. Water levels in all of these canals are controlled and maintained by a network of District and local structures.

Canal-aquifer interactions are included in the model through use of the River and Drain packages. The canals in the region were classified as both rivers and drains depending upon their connections to the regional system. In either case, the required input data included canal stages along with conductance terms depicting the degree of hydraulic interaction between the canals and the aquifer. Canal stages were assigned to the various

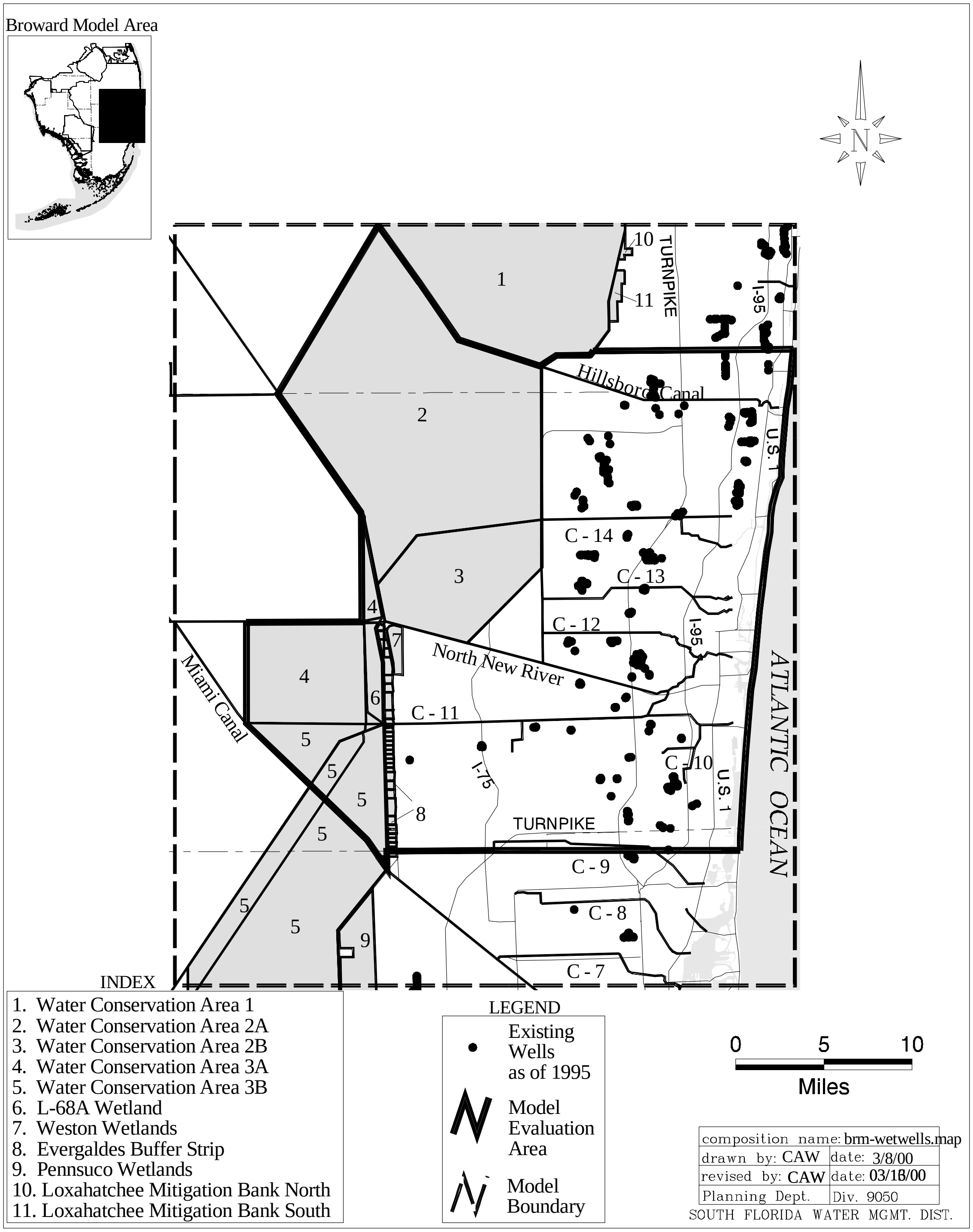

Figure F-7. Model Boundaries and Major Features of the Broward County Ground Water Flow Model.

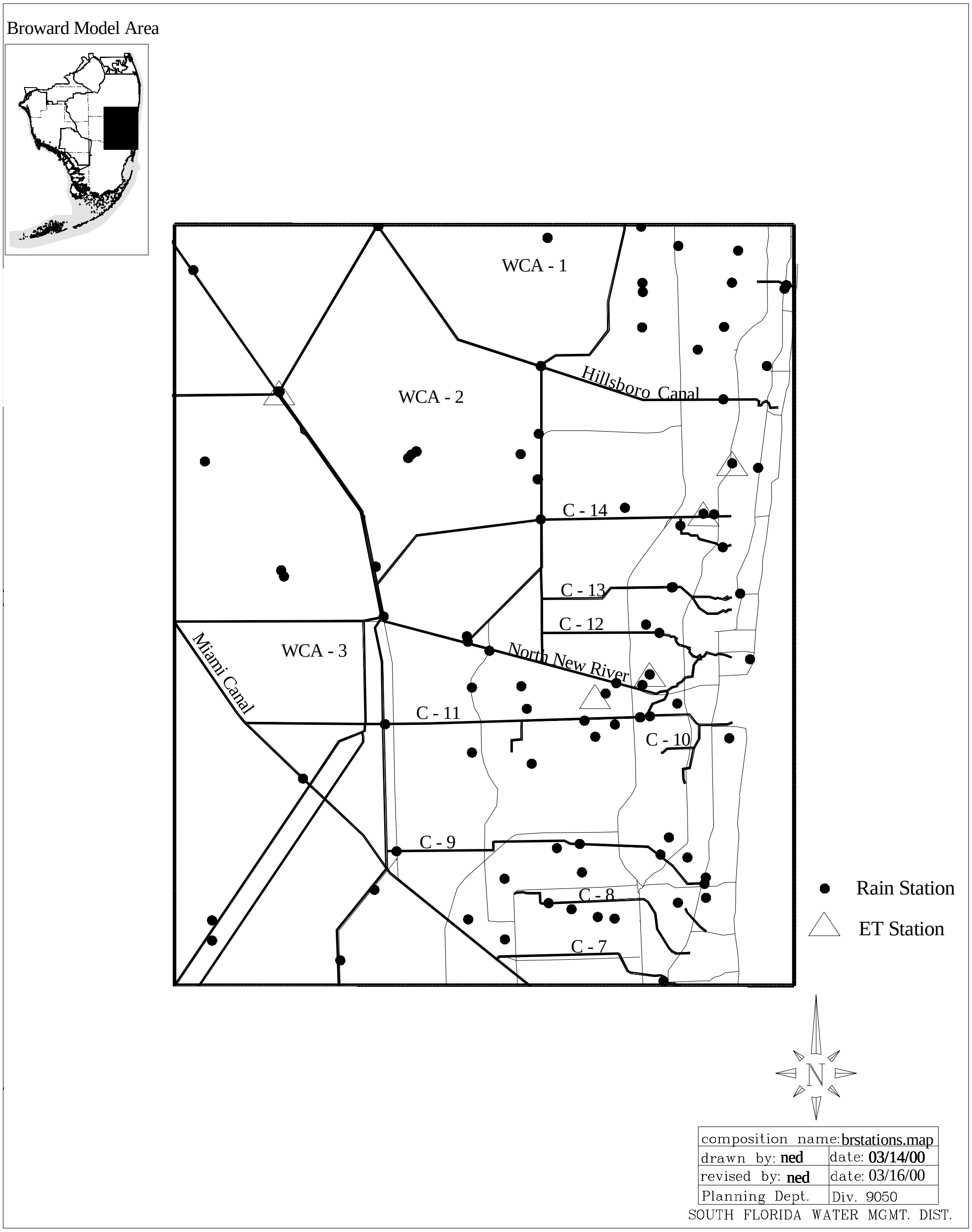

Figure F-8. Rainfall and Evapotranspiration Station Locations used in the Broward County Ground Water Flow Model.

canal reaches by using observed or simulated water levels from the SFWMM, depending upon the scenario at stage monitoring stations to estimate hydraulic grade line elevations within each reach. A third package utilized in the model was the seepage collection system around the proposed reservoirs. This option simulates the removal of water from a canal and subsequent discharge back into the reservoir systems.

Wetlands

The major wetland systems within the active model area include all or portions of WCA-1, WCA-2A, WCA-2B, WCA-3A, WCA-3B, the Everglades Buffer Strip and a number small wetland systems located east of the East Coast Protective Levee. Ground water levels, structure discharges, rainfall, ET, and topography influence surface water elevations within these wetlands.

The Wetlands package (Restrepo et al., 1998) was used to simulate overland flow within the wetland systems along with interactions between the surface water and ground water. Topographic features influencing the rate of movement through the wetlands (i.e., levees, sloughs, and air boat trails) are explicitly represented in the wetlands package.

Water Use

Ground water withdrawals in Broward County are primarily concentrated in Public Water Supply (PWS), and golf course, landscape, and agricultural irrigation. All permitted withdrawals are explicitly represented in the modeling through the wells package.

Demands for irrigation users were based on the permitted average annual demand. For PWS users, information contained in monthly water use reports submitted to the District was used to assign monthly pumpage rates to each utility. Monthly distributions were based upon the historical record. Actual annual demands were based upon the historical record or projected demand as shown in **Table F-7**, depending upon the simulation. The resulting mean daily pumpage for each utility was then divided among its wells according to a specified percentage for each well.

Features of the Outer Boundary

As shown in **Figure F-1**, the portion of the outer model boundary located east of the levees consists of the following:

- A coastal boundary
- A northern boundary located along the C-15 Canal and southern boundary along the C-6/C-7 canals
- A western boundary within the Everglades

Along the coastal boundary, the required stages and conductance values were determined in the manner explained in the **General Subregional Model Features** section

Table F-7. Public Water Supply Demands on the Surficial Aquifer System by Utility.

Utility	Permit #	Average Annual Demands (MGY)		Average Daily Demands (MGD)	
		1995 Base	2020 Base	1995 Base	2020 Base
North Palm Beach (NPB)					
Town of Jupiter	50-00010-W	3,463.85	4,818.00	9.49	13.20
Mangonia Park	50-00030-W	122.90	122.90	0.34	0.34
Tequesta	50-00046-W	512.97	638.75	1.41	1.75
Seacoast	50-00365-W	5,276.22	10,369.65	14.45	28.41
Riviera Beach	50-00460-W	3,270.72	4,275.00	8.96	11.71
Good Samaritan Hospital	50-00653-W	127.75	135.05	0.35	0.37
PB Park Commerce	50-01528-W	3.65	357.00	0.01	0.98
Total for NPB Service Area		12,778.06	20,716.35	35.01	56.76
LEC Service Area 1 (LECSA1)					
Deerfield Beach	06-00082-W	4,000.42	4,069.00	10.96	11.15
Parkland	06-00242-W	74.48	112.00	0.20	0.31
North Springs	06-00274-W	515.62	1,715.50	1.41	4.70
Palm Springs	50-00036-W	1,465.87	2,292.20	4.02	6.28
Atlantis	50-00083-W	17.68	0.00	0.05	0.00
PBC (Palm Bch Co) (2W,8W)	50-00135-W	6,821.62	10,442.65	18.69	28.61
Tropical MHP	50-00137-W	33.29	0.00	0.09	0.00
Delray Beach	50-00177-W	4,441.69	5,810.80	12.17	15.92
Century Utilities/PBC	50-00178-W	152.42	0.00	0.42	0.00
Jamaica Bay	50-00179-W	0.00	0.00	0.00	0.00
Lake Worth	50-00234-W	2,611.92	3,556.50	7.16	9.74
Highland Beach	50-00346-W	411.27	508.00	1.13	1.39
Boca Raton	50-00367-W	13,106.54	17,136.75	35.91	46.95
PBC System (3W, 9W)	50-00401-W	5,719.56	16,516.25	15.67	45.25
Royal Palm Beach	50-00444-W	803.70	0.00	2.20	0.00
ACME (Wellington)	50-00464-W	1,475.09	3,504.00	4.04	9.60
Boynton Beach	50-00499-W	3,226.66	6,278.00	8.84	17.20
Manalapan	50-00506-W	365.86	474.50	1.00	1.30
Nat'l MHP (Worth Village)	50-00572-W	70.24	97.00	0.19	0.27
Lantana	50-00575-W	752.29	890.60	2.06	2.44
Lion Country Safari	50-00605-W	18.49	42.00	0.05	0.12
Village of Golf	50-00612-W	152.66	196.00	0.42	0.54
City of West Palm Beach[a]	50-00615-W	9,206.80	15,330.00	25.22	42.00
AG Holley (St of FL)	50-01092-W	24.70	85.00	0.07	0.23
Arrowhead	50-01283-W	0.00	0.00	0.00	0.00
United Technologies	50-00501-W (old) 50-01663-W	212.57	408.80	0.58	1.12
Total for LEC Service Area 1		55,681.44	89,465.55	152.55	245.11
LEC Service Area 2 (LECSA2)					
Seminole Tribe	06-00001-W	126.70	321.15	0.35	0.88
Royal Utility Company	06-00003-W	133.05	149.00	0.37	0.41
North Lauderdale	06-00004-W	1,107.97	2,299.50	3.04	6.30
Hollywood	06-00038-W	7,048.74	8,030.00	19.31	22.00
Miramar	06-00054-W	1,529.04	4,504.10	4.19	12.34
Pompano	06-00070-W	5,929.80	7,300.00	16.25	20.00
Tamarac	06-00071-W	2,044.49	3,650.00	5.60	10.00
Coral Springs I/D	06-00100-W	1,488.85	1,752.00	4.08	4.80

Table F-7. Public Water Supply Demands on the Surficial Aquifer System by Utility. (Continued)

Utility	Permit #	Average Annual Demands (MGY)		Average Daily Demands (MGD)	
		1995 Base	2020 Base	1995 Base	2020 Base
Hillsboro Beach	06-00101-W	313.85	360.00	0.86	0.99
Coral Springs City	06-00102-W	2,642.64	3,525.90	7.24	9.66
Plantation	06-00103-W	5,082.17	6,293.00	13.92	17.24
Sunrise	06-00120-W	6,612.50	11,351.50	18.12	31.10
Margate	06-00121-W	3,045.09	4,124.50	8.34	11.30
Ft. Lauderdale	06-00123-W	17,791.10	21,900.00	48.74	60.00
Lauderhill	06-00129-W	2,712.21	2,887.10	7.43	7.91
Davie	06-00134-W	1,112.42	1,929.00	3.05	5.29
Pembroke Pines	06-00135-W	3,405.35	7,300.00	9.33	20.00
Hallandale	06-00138-W	1,261.06	1,277.50	3.45	3.50
Broward 2A (east)	06-00142-W	5,305.05	4,015.00	14.53	11.00
Broward 3A/3C (Picolo)	06-00145-W (old) 06-01474-W	964.80	5,657.50	2.64	15.50
Broward 1A,1B	06-00146-W	3,406.95	4,380.00	9.33	12.00
Broward 3B	06-00147-W (old) 06-01474-W	793.50	0.00	2.17	0.00
Ferncrest	06-00170-W	285.35	401.00	0.78	1.10
Dania Beach	06-00187-W	898.93	730.00	1.85	2.00
Cooper City	06-00365-W	1,278.26	2,226.00	3.50	6.10
South Broward	06-00435-W	241.89	0.00	0.66	0.00
Broward North Regional	06-01634-W	0.00	1,825.00	0.00	5.00
Total for LEC Service Area 2		76,561.76	108,188.75	209.13	296.41
LEC Service Area 3 (LECSA3)					
FKAA[b]	13-00005-W	5,136.91	6,935.00	14.07	19.00
Alexander Orr (WASD)	13-00017-W	61,375.50	103,065.05	168.15	282.37
Florida City	13-00029-W	837.97	1,025.65	2.30	2.81
WASD- Hialeah Preston	13-00037-W	60,875.50	76,723.00	166.78	210.20
REX (WASD-S Dade)	13-00040-W	2,209.80	17,395.90	6.05	47.66
Homestead	13-00046-W	2,354.09	5,694.00	6.45	15.60
North Miami	13-00059-W	2,622.19	3,252.55	7.18	8.91
North Miami Beach	13-00060-W	5,618.61	10,950.00	15.39	30.00
Opa Locka	13-00065-W	0	0	0	0
Homestead AFB	13-00068-W	377.80	0.00	1.04	0.00
Total for LECSA 3		141,408.37	225,041.15	387.41	616.55
LEC Planning Area Total		286,429.63	443,411.80	784.10	1,214.82

a. Demand figures are from surface water.

b. Demand figures are to supply Monroe County.

of this appendix beginning on **page F-5**. To represent the wedge-like shape of the saltwater interface (Sonenshein and Koszalka, 1996), the location of the boundary cells move inland in the deeper layers of the model. For planning simulations, the coastal boundary, like all of the other outer boundaries, was incorporated into the model using the General Head Boundary package.

Along the northern boundary, stages were based on water levels in canals while the conductance terms were computed in each model layer using the hydraulic conductivity values and dimensions of the boundary cells.

Along the western boundary, heads were fixed using historical and simulated data from District canals corresponding to the boundary. In areas along Alligator Alley, where a canal was not present, average values for northeastern WCA-3A were utilized. The conductance values for these sections of the model boundary were based on the same information used to compute conductance values along the northern and southern boundaries.

Model Calibration

The period of record selected for history matching was 1988-1995. This period of record includes a severe drought (1988-1990), an average condition (1992-1993), and an extreme wet condition (1994-1995). The primary objective for the history matching was to compare measured and computed water levels at monitoring sites and adjust model parameters as appropriate to reduce errors to an acceptable level.

Differences between computed and observed water levels are summarized in **Table F-8**. Also provided are mean, minimum, and maximum errors for each site. Due to time constraints and model coverage, calibration of the model in the eastern Boca Raton area was not considered at this time.

It is important to note that the statistics for each gage are based on the measured water level data available at that site within the calibration period of record. At some gages, data only exist over a fraction of the total period of record and result in statistics that may not be indicative of model accuracy over the entire period of record. Furthermore, the measured ground water levels are the daily maximum values (the only ground water levels published by the USGS) at each site and may not always be close to observed end-of-day ground water levels. In contrast, the model computes water levels at the end of each time step, which, in this case, is the end of each day. Additionally, one can generally not expect a finite-difference based model to replicate ground water levels observed in the immediate vicinity of a pumping well due to limitations imposed by the spatial resolution of the model. Finally, it should be emphasized that the calibration results depicted in **Table F-8** reflect the current status of the model and are subject to change as improvements to the model are made.

Recommendations and Conclusions

Model Capabilities and Limitations for Applications

The preceding discussions suggest that the model, in its current state, is adequate for comparative type analyses where water level based performance measures for various water supply alternatives are compared in order to select the most appropriate alternative(s) to undergo more detailed analyses. The locations of such performance measures should be within the evaluation area discussed previously. Furthermore, it is

Table F-8. Differences Between Computed and Observed Water Levels.

STATION	Minimum Difference	Average Difference	Maximum Difference	Percent
G-1260	0	1.234	3.69	44.95
G-2030	0	0.3916	1.92	94.087
G-2739	0	0.3696	2.4	96.7438
G-1213	0	0.7065	5.24	70.9022
G- 616	0	0.6586	4.3	80.2497
G-1315	0	0.9017	2.91	60.7533
G-1215	0	1.2699	4.9	50.4383
G-2031	0	0.3876	2.07	96.2377
G-2147	0	0.8442	2.95	60.5865
G-1316	0	0.5788	2.57	89.8757
G- 853	0	1.147	3.58	45.5946
G-2443	0	0.3285	2.01	97.479
G-2444	0	1.1182	8.59	53.52
G-2395	0	1.35	4.69	42.9821
G- 820A	0.02	1.4157	3.9	24.2903
G-2033	0	0.4002	3.39	95.292
G-2032	0	0.3639	2.86	95.3366
G-1220	0	0.431	2.64	92.9142
G-2376	0	0.7072	1.87	74.5623
S- 329	0	0.8324	4.15	64.1571
G- 561	0	0.8809	3.49	62.6502
G- 617	0	0.2951	2.3	97.2279
G-2494	0	0.3486	1.5	96.0674
G-2490	0	0.413	1.65	88.5942
G-1221	0	0.2503	4.89	96.7067
G-2488	0	0.6764	1.98	76.584
G-2487	0.01	0.6109	2.04	75
G-2491	0	0.4695	1.73	83.5106
G-2493	0	0.3266	1.19	96.2766
G-2492	0	0.3332	1.22	93.883
G-1224	0	0.7474	3.36	72.1079
G-1322	0	0.3564	1.39	97.0769
G-1223	0	0.4111	3.18	96.3976
G-2495	0	0.5801	1.97	87.381
G-2034	0	0.4525	2.46	91.761
G-2854	0.41	0.9081	1.67	63.8554
G-2615	0.34	0.7954	1.51	63.8554
G-2856	0.39	0.8787	1.44	58.6957
G-2614	0.16	0.7457	1.56	63.8554
G-1226	0	0.4904	7.87	91.2806

Table F-8. Differences Between Computed and Observed Water Levels.

STATION	Minimum Difference	Average Difference	Maximum Difference	Percent
G-2035	0	0.4712	3.88	91.4968
G-1225	0	0.5557	3.15	86.0888
G-1222	0	0.5006	2.4	89.6467
F- 291	0	0.4916	3.87	87.3575
G-1473	0	0.3636	3.52	93.2759
G-1472	0	0.4582	3.06	87.6667
G-1636	0	0.3191	2.18	97.5009
G- 970	0	0.3552	2.58	98.9183
G-1637	0	0.4488	1.79	93.7478
G-3571	0.01	0.5444	3.9	90.6801
S- 18	0	0.2469	2.32	99.2662
G- 852	0	0.2715	2.94	97.6349
G-1166	0	0.2358	2.31	98.3635
CA2B.T	0	1.5231	5.02	33.2188
CA2A300	0.02	1.0553	2.19	47.1976
2A-17_B	0	0.6866	1.89	75.9754
WCA2F1	0	0.8642	1.74	56.4815
WCA2F4	0	0.5317	1.3	92.8241
WCA2E4	0.01	0.4615	1.18	96.5358
WCA2U1	0	0.3433	1.24	96.0739
WCA2RT	0	0.3082	1.15	98.7245
WCA2E1	0.01	0.7699	1.49	63.109
2-15	0	0.5126	1.1	98.2911
2-17	0	0.8124	1.94	66.3317
3-63	0	0.343	1.76	97.2871
3-76	0	0.2799	1.11	99.4859
1-9	0	0.3175	1.17	96.1063
PB-0732	0	0.5067	2.17	87.3835
PB-1661	0	0.3231	3.13	95.8739
PB-1680	0	0.5655	2.88	86.1718
PB-1684	0.26	0.9488	2.79	67.5134
PB-0490	0	0.45	1.88	90
PB-0492	0.03	0.6194	3.7	84.058
PB-0567	0	0.5566	2.41	82.3529
PB-0948	0	0.5185	1.44	89.7436
PB-1006	0.01	0.3967	1.64	93.0233
PB-1063	0	0.5914	1.88	83.908
PB-0897	0.04	0.7574	2.38	69.7674

suggested that only water levels be used to formulate performance measures since all of the history matching work completed so far has been limited to water levels. Ground water flows and canal base flows computed by the model should be used with caution. In either case, it is recommended that the effect of uncertainties in model input on model based alternative comparisons be assessed prior to making any final decisions regarding alternative selections.

Future Improvements

Certain improvements to the model are recommended in order to enhance its ability to support future applications. Such enhancements should include, but not necessarily be limited to, the following:

- Calibration of the model in the east Boca Raton area
- Acquisition of data and ground truthing of canal base flows and canal-aquifer interation of simulated to actual conditions
- Inclusion of a saltwater simulation package to provide a clear understanding of potential movement of the saline interface
- Improved water shortage trigger location and activation levels to provide adequate coverage for the model domain